Title of the Invention

ACTIVE NOISE CONTROLLER AND PROJECTOR USING THE SAME

Background of the Invention

This invention relates to an active noise controller used in a household electric appliance or business-oriented appliance such that the temperature inside its structure is controlled by forced air flow generated by rotation of a cooling fan, and specially to a technology of reducing acoustic noise of the cooling fan used in a projector having a high-power lamp.

In liquid crystal projectors, partly because luminous energy of the lamp that is not used effectively changes mostly to heat, the inside of the apparatus becomes high temperature and hence it is indispensable to cool the inside. For this reason, cooling inside the apparatus is achieved by forced air flow generated by the cooling fan. At this point, it should be noted that regarding the acoustic noise generated by the cooling fan, low acoustic noise is achieved statically by modifying the shape of the fan, the rotation speed, and a method of driving the fan or by optimizing structural materials of the apparatus, a duct design, etc. under restrictions of apparatus volume.

Further, as disclosed in JP-A Nos. 8581/1994 and 20866/1998, methods of achieving low acoustic noise dynamically -- muffling the noise through an interference action -- by detecting the acoustic noise generated by the cooling fan and generating an acoustic wave component of an antiphase waveform have been proposed. Being not limited to this, a lot of active noise

control techniques using an antiphase wave have been proposed.

Summary of the Invention

In the liquid crystal projector, improvement toward high luminance by the use of a high-power lamp and compact size of the apparatus have become main factors that disadvantageously increase restrictions in designing an air flow path. In low acoustic noise in the conventional static technology, optimization of the design of air flow path is conducted in order to maintain and improve efficiency of radiator, and the air flow rate is secured by multiply the number of cooling fans and increasing the rotation speed of each cooling fan. However, in view of a trade-off between the acoustic noise and performance of the projector, improvement in luminance performance and size reduction of the projector come with several problems, such as occurrence of restrictions in the design.

On the other hand, the methods disclosed in the patent publication are ones of active noise control that can be applied to only apparatuses that are cooled by a single cooling fan, and further, variation in the rotation speed of the cooling fan (speed drift) is not considered.

In view of the conventional technology, the object of this invention is to provide an active noise controller that realizes low acoustic noise at low cost with a high degree of accuracy, and a projector that achieves high luminance and compact size using this controller.

In order to solve the problems, this invention is directed

to an active noise controller equipped with fans each having a plurality of vanes and a duct for guiding wind from the fan, the controller comprising: a microphone for taking in the acoustic noise in the duct; rotation speed detecting means for detecting the fan rotation speed; frequency calculating means for calculating base and multiple frequencies based on the rotation speed and vane numbers of the fan; analyzing means for analyzing the acoustic noise that was taken in with the microphone in a time sequential manner for each of base and multiple frequencies that were calculated by the frequency calculating means; phase controlling means for controlling the phase of the acoustic noise at each of the base and multiple frequencies in a time sequential manner; and signal generating means for generating a driving signal based on the analyzing means, the frequency calculating means, and the phase controlling means, wherein the active noise controller is configured to drive a speaker with the driving signal generated by the signal generating means.

This invention makes possible a low-priced, highly accurate active noise controller and a projector.

Brief Description of the Drawings

FIG. 1 is a block diagram showing a method of active noise control that is carried into practice by the first embodiment according to this invention;

FIG. 2 shows a projector of the first embodiment according to this invention;

FIG. 3 is a timing chart 1 that gives supplementary illustration of the first and second embodiments; and

FIG. 4 is a timing chart 2 that gives supplementary illustration of the first and second embodiments.

Detailed Description of the Preferred Embodiments

Hereafter, the embodiments according to this invention will be described referring to the drawings.

[Embodiment 1]

FIG. 1 is a block diagram showing an example of the active noise controller according to this invention. FIGS. 3 and 4 are timing charts showing the outline of processing.

In FIG. 1, the reference numerals denote respective constituents as follows:

1, 2 fans each having the vane numbers K (e.g., K=7),

3 a duct structure constituting the air flow path of wind,

4 a microphone,

5 a speaker,

6 a filter and amplifier for input compensation,

7 an ADC (analog-digital-converter) for converting an analog signal to a digital signal,

8 a filter and amplifier for output compensation,

9 a DAC (digital-analog-converter) for converting a digital signal to an analog signal,

10 a rotation speed controller,

11 a rotation speed detector,

12 a frequency counter for fan rotation,

13 a digital signal processor (referred to as DSP),

14 a filter,

15 a frequency analyzer,

16 a remaining noise judgment part,

17 a time sequential controller,

18 a rotation time detector,

19 a look-up-table (referred to as LUT),

20 is a frequency (f-value) selector,

21 an amplifier and phase controller,

22 a wave data generator,

23, 24 antiphase wave generator units each composed of constituents 19 to 22 for each fan, and

25 an adder.

FIGS. 3 and 4 show the timing in each image-processing section.

Here, if the acoustic noise is observed while the fan 1 is being rotated, the amount of noise at specific frequency components protrudes, as is well known. For example, when the fan makes M rotations (e.g., M = 3000) for 1 minute, it is known that the noise base frequency NZ is determined by the formula below (formula 1) with the rotation speed M and the vane numbers K.

$$NZ = M/60 \times K \; (= 3000/60 \times 7 = 350\ Hz) \qquad \text{(Formula 1)}$$

When the rotation speed M = 3000 and the vane numbers K = 7, the noise base frequency is NZ = 350 Hz, the amount of noise at its multiple frequencies (NZ×2, ×3, ×4,···) protrudes. If

the noise components are undesirable in the audible frequency band, they jar unpleasantly on the ear.

Hereafter, a method of actively controlling the noise base frequency NZ and its multiple frequencies that jar unpleasantly on the ear will be described in detail.

Note here that, in order to make the explanation short in this embodiment, the case is limited as follows: two identical fans each having the vane numbers of seven are used, and target noise components of each fan are two components (the above-mentioned NZ and NZ×2); therefore, total four frequency components are actively controlled. It is needless to say that a similar effect may be achieved even if any of the vane numbers, the fan numbers, and the number of target noise components is increased or decreased or a fan shape is modified. Moreover, the structure of air flow path is as shown with a rectangle type passage. It is needless to say that similar effect may be achieved even if an apparatus to be targeted is configured to have an optimal structure.

According to a rotation instruction not shown in the figure, the rotation speed controller 10 controls the rotation of the fan 1 to be the above-described rotation speed M and the rotation speed of the fan 2 to be a rotation speed L with driving signals 10c, 10d, respectively. In this case, the rotation speed M of the fan 1 and the rotation speed L of the fan 2 are determined to have a relation $M \neq L$ so that any higher-order frequency component of the noise frequency that is determined by the information of frequency and the vane numbers may not be identical

among fans.

Rotation operations of the fans 1, 2 generate air flow in the air flow path made of a duct structure 3, and the microphone 4 monitors an acoustic noise state in the duct structure 3. Alternately, the processing may be done in such a way that the microphone 4 does not hinder the air flow. A microphone signal is subjected to simple noise reduction of low frequencies and high frequencies and various signal compensations, such as amplification of signal level in the filter and amplifier 6, and is then converted to a digital signal with a sampling frequency of Fs (Hz) by the ADC 7.

On the other hand, the DAC 9 converts a digital signal of actively noise controlling wave that was outputted from the adder 25 to an analog signal, which is subjected to removal of unnecessary frequency components and noises and then amplification in a filter and amplifier for output compensation 8, and drives the speaker 5. A sound pressure vibration by the speaker 5 is made to emit inside the duct structure 3. In this case, the active noise controller is configured in such a way that the sound pressure vibration may not leak to the rear face of the speaker 5 (outside the duct structure 3).

The rotation speed detector 11 generates one pulse/rotation signals 11a, 11b by the use of an Hall device signal, an FG signal, a photosensor signal, etc. as rotational information 10a, 10b of the fans 1, 2 to be used by the rotation speed controller 10. The frequency counter 12 outputs: interrupt (1) 12a and interrupt (2) 12b that serve as reference

timings in performing a calculation for phase adjustment in synchronization with one pulse/rotation signals 11a, 11b from these signals; and information of frequency 12c, 12d by measuring the rotation frequencies of the fans 1, 2.

The DSP 13 is one that performs digital arithmetic processing, and will be illustrated below with processing in its each part assumed as a piece of hardware configuration in order to make explanation easier to understand. Moreover, in this embodiment, the case where the DSP is used is shown, but embodiments are not limited to this. Needless to say, any processor having the same processing function is applicable to this invention.

First, the filter 14 processes the digital signal of the ADC 7 using a filter that assumes a filter characteristic for extracting signals in frequency bands of desired targets from the digital signal. The frequency analyzer 15 selects and extracts the amount of the acoustic noise of frequency components specified by a frequency selector 20 that will be described later, and judges a noise reduced level from a residual state of the amount of the acoustic noise in the remaining noise judgment part 16. In this case, the remaining noise judgment part 16 is configured to prevent erroneous judgments caused by impulse disturbance resulting from the ambient circumstances (for example, the active noise controller may suffer various kinds of daily life sounds, such as speaking sound, slapping sound, clapping sound, sound of door's opening and shutting). Specifically, in judging the noise reduced level by detecting

the noise levels of the frequency components according to the time sequential control permission signal 17c from the time sequential controller 17, the active noise controller is configured to perform the judgment considering the past noise levels of the frequency components. For example, the active noise controller calculates a histogram for noise level, eliminates a range of level except the desired noise level to get a modified noise level, and performs the judgment based on this level.

Using interrupts 12a, 12b as references, the rotation time detector 18 generates: a reference 18b of the rotation speed for each of the fans 1, 2; a base phase 18a of an actively noise controlling wave for each of the fans 1, 2; and a time sequential timing signal 18c with respect to the counting of the rotation speed of the fan 1.

The time sequential controller 17 issues a control permission signal that indicates either control permission or control prohibition for each of noise components (four components) of each fan with respect to the time sequential timing signal 18c in a time sequential manner (in timing diagrams 17a, 17b in FIGS. 3 and 4, LOW: permission period, HIGH: prohibition period). Here, since there is the possibility that rotation phases of the two fans may agree with each other, the active noise controller is configured to perform a time sequential operation relative to one of the reference timings (12a) to which the operation for phase adjustment is performed. FIGS. 3 and 4 show an example in which a generation method of time sequential

control permission signals 17a, 17b is changed. In this example, a permission period issuing method is not limited at all, but is defined to be optimal to constituting conditions of a target frequency.

The LUT 19 takes in various kinds of frequency characteristics of the structure, the ambient environment, the speaker, and the microphone, and outputs an amplitude compensation value 19a and a phase compensation value 19b that correspond to information of a target frequency to be actively controlled by the frequency selector.

The frequency selector 20 determines the base frequency (NZ) and the second-order frequency (NZ×2) that are governed by the information of frequency (= M/60) 12c, 12d and the vane numbers (K=7) of the fan. In determining these frequencies, since the fans 1, 2 rotate with some degree of rotational fluctuation (jitter), the frequency selector 20 may be configured to smooth information of frequency 12c, 12d relative to the counting of rotation speed 18b.

The amplifier and phase controller 21 performs the following processing for each acoustic noise component of each fan. That is, in a period when the time sequential control permission signals 17a, 17b indicate the permission period, the amplifier and phase controller 21 controls the amplitude value and the phase shift quantity so that the amount of remaining noise by a judgment result of the remaining noise judgment part 16 becomes the minimum. Then, the amplifier and phase controller 21 generates an amplitude value 21a and a phase shift quantity

21b that are the result of addition of the above-mentioned amplitude value and the amplitude compensation value 19a from the LUT 19 and the result of addition of the above-mentioned phase shift quantity and the phase compensation value 19b therefrom, respectively. On the other hand, in the prohibition period, the amplifier and phase controller 21 maintains and outputs the amplitude value 21a and the phase shift quantity 21b that were determined in the past permission period. Even in a period when it is judged as the prohibition period or in the noise reduced level, if there is a change in the information of frequency 12c, 12d, the amplitude value 21a and the phase shift quantity 21b may be compensated using an amplitude compensation value 19a and a phase compensation value 19b by the LUT 19.

Wave data generator 22 forms antiphase waves with respect to the fan noise components from pieces of information: four target frequencies of the fans 1, 2 obtained by the frequency selector 20, rotation base phase 18a, the amplitude value 21a, and the phase shift quantity 21b.

Here, the reference numerals 23, 24 denote antiphase wave generator units each composed of the LUT 19, the frequency selector 20, the amplifier and phase controller 21, and the wave data generator 22; and the active noise controller is shown as of a configuration that has as many units as the fans to be actively sound controlled (in this embodiment, two units). Needless to say, the number of the antiphase wave generator units is not limited to the number of the fans, and even when using as many

antiphase wave generator units as target frequencies, a similar effect may be obtained.

The adder 25 adds four antiphase wave components obtained by the above-mentioned processing, and outputs the addition result to the DAC 9.

According to the first embodiment described is configured such that frequencies that jar unpleasantly on the ear are specified as target frequencies to be actively controlled and that the rotation speed is made to differ among a plurality of fans, thus enabling classification of acoustic noise states to be simplified and also extraction of remaining noise components and the above-mentioned calculation to be simplified. Thereby, it becomes possible to reduce a calculation amount required by the DSP (digital-signal-processor), permitting selection of a low-priced DSP having lower processing capability. Moreover, since the frequency components are specified, it becomes possible to simplify signal compensation of the microphone signal and the speaker driving signal. In addition to this, since high-grade and highly accurate analog parts are not required, it becomes possible to reduce parts count and parts cost.

The method is one that directly detects the rotation speed(s) and the rotation phase(s) of the fan(s), there is neither increase in the calculation amount caused by continuous evaluation of constantly measured noise level and continuous following of the phase for detecting a fan rotation state nor delay in a follow-up control caused by delay in arithmetic processing, and further there is no fear that the control goes

into oscillation in some very extreme cases. Therefore, it is easily possible for the active noise controller to follow even fan rotation jitter that occurs irregularly without going into oscillation.

Since the fan rotation speed and the rotation phase are directly detected and when generating the antiphase wave, it is done relative to the rotation phase of the fan, the frequency and the phase are fixed automatically by the antiphase wave and fan rotation; and consequently, no special arithmetic processing is required.

The antiphase wave conditions are reexamined and used for control alternately in a time sequential manner. Thus even when the target frequencies are increased, needless increase in a peak calculation amount in the DSP may be prevented.

Since the target frequencies are specified, even if an impulse disturbance occurs, such a disturbance except the specified frequencies is ignored. Even if the frequency of the disturbance agrees with one of the specified frequencies, since the apparatus is configured to consider the past noise level of the frequency component as described above, the disturbance is rejected. Thereby, it becomes easily possible to prevent oscillation of the antiphase wave caused by the disturbance.

In the form of this embodiment, the configuration is limited and described. Needless to say, this invention is not limited to this embodiment, and certainly, this invention may be applied to a case where location of the processing part, which was described to be either inside the DSP or outside the DSP,

is changed.

[Embodiment 2]

Next, the second embodiment of this invention will be described referring to FIG. 2. Note that since each part designated with the same reference numeral described in the first embodiment has almost the same function, description thereof is omitted to avoid repeated description. In this embodiment described is a liquid crystal projector as one of image display apparatuses. In FIG. 2, the reference numerals denote respective constituents as follows:

26 a temperature sensor for measuring the temperature inside the liquid crystal projector,

27 a system controller for controlling a system of the liquid crystal projector,

28 a lamp driver,

29 a lamp,

30, 32 an optics composed of a lens, a filter, etc., respectively,

31 is a light valve,

33 a screen.

The liquid crystal projector has a configuration such that parts of the lamp 29, the optics 30, the light valve 31, and the optics 32 are disposed inside the duct 3.

As brightness adjustment of the projected image by the liquid crystal projector, there is a method of realizing increase and decrease in the amount of light of the lamp 29 by the lamp driver 28 increasing/decreasing lamp driving electric power

according to a target lamp power level from the system controller 27.

In this case, the amount of heat generation inside the duct 3 increases and decreases depending on increase/decrease in the lamp driving electric power. Accordingly, the air flow rates necessary for controlling the temperature inside the duct 3 are different to each other. Then, the liquid crystal projector controls in such a way that an optimal air flow rate may be obtained considering a trade-off between the acoustic noise of itself and the air flow rate.

For example, the temperature inside the projector is measured with the temperature sensor 26, and the system controller 27 controls the rotation speed controller 10 by controlling electric power of the lamp driver 28 and by issuing a rotation speed indication signal (target value) so that an optimal air flow rate is obtained.

In this case, the system controller 27 obtains information of noise reduced level inside the liquid crystal display from the remaining noise judgment part 16, and controls the fan rotation speed so that it varies mildly within a range that the active noise control could follow it.

According to the second embodiment described in the foregoing, in an image display apparatus such that the rotation speed of the cooling fan is controlled according to the temperature inside the apparatus, such as th liquid crystal projector, it becomes easily possible to realize it by this method while maintaining the noise reduced level without generating

oscillation even when the fan rotation speed is varied. This invention relates to a liquid crystal projector and thus may be employed for an image display apparatus of a liquid crystal projector as a low price consumer appliance with the function of actively controlling noise without malfunction and oscillation regardless of several disturbance factors of the surrounding environment described in the first embodiment, such as of speaking sound, sound caused by desk work, clapping sound, and of sound of door's opening/shutting.

In the foregoing, embodiments are limited to a case where a plurality of fans is used, but this invention may be applied to an apparatus with a single fan. In such a case, since the amount of processing is decreased, the number of controls may be increased or a low calculation amount DSP may be adopted, whereby following speed to the acoustic noise may be easily improved o r the cost may be easily reduced, respectively.

Where a plurality of openings of the structure 3 is provided in an apparatus, a plurality of the same systems may be used. Alternatively, speakers and microphones may additionally be provided and the same processing may be performed in the DSP in parallel (in a time sequential manner). In either modification, a similar effect may be obtained.

The embodiment according to this invention was described in the case where its application was a liquid crystal projector in a limited way. However, the application is not limited to this particular apparatus. A similar effects may be achieved in the case where this active noise controlling system is applied

to an image display apparatus in which cooling inside the apparatus is done by air flow generated by a fan or apparatuses other than this. A similar effect may be realized with similar processing. For example, there are a lot of such applications as refrigerator, air cooling fan (indoor equipment/outdoor equipment), various kinds of engines, air cleaner, PC, and the like. On the other hand, it is easy to achieve further lower acoustic noise by using this in combination with a heat pipe, a liquid cooling system, etc.

According to this invention, by virtue of selection of a low-priced DSP because of a low calculation amount and reduction in analog parts count, a simple and low-priced active noise controller may be provided. Furthermore, in the projector such that the rotation speed of the cooing fan is controlled according to the temperature inside the apparatus, such as the liquid crystal projector, application of this invention enables the projector to have an active noise control effect free from malfunction and oscillation caused by following to variation in the fan rotation speed and ambient disturbances, and makes it possible to realize such a low price as one can use it for a consumer appliance.

Needless to say, this invention may be applied not only to the image display system but also to other apparatuses that have cooling fans, and similar effect of active noise control may be obtained by the similar processing.